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**Patentanmeldung Nr. Patent application No. Demande de brevet n°**

01205146.2

**PRIORITY DOCUMENT**

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Der Präsident des Europäischen Patentamts; Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets p.o.

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If no title is shown please refer to the description.
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Method for interconnecting tubelars by forge welding

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# METHOD FOR INTERCONNECTING TUBULARS BY FORGE WELDING

## BACKGROUND OF THE INVENTION

The invention relates to a method and system for interconnecting tubulars by forge welding.

It is known from US patent 4,669,650 to forge weld tubular ends in a reducing environment, wherein a flushing gas, for example hydrogen having less than 100 ppm $H_2O$ and/or $O_2$ is flushed around the heated tubular ends to inhibit corrosion and to reduce and flush off an oxidized skin. A disadvantage of using hydrogen as flushing gas is that it will react with oxygen in the atmosphere in an explosive fashion so that it cannot be used in hazardous areas such as on an offshore oil and/or gas production platform or on an oil and/or gas well drilling rig. This prior art reference mentions on page 2, lines 65-68 that instead of using a reducing gas an inert gas may be used as flushing gas and discloses that the tubular end may be heated by means of an induction coil or by means of an unspecified method of high frequency heating.

International patent application WO98/33619 discloses a method for joining oilfield tubulars by diffusion bonding, wherein the tubular ends are heated by an induction coil inside a cavity filled with a shield gas.

European patent 0396204 discloses a method for friction welding of well tubulars, wherein a ring is rotated at high speed in a cavity filled with shield gas and the tubular ends are pressed against the ring whereupon the ring and tubular end melt together.

US patent 5,721,413 discloses a method of heating closely spaced portion of two pipes by heating each pipe end by a pair of diametrically opposite contacts, and the contacts of each pair are arranged in a specific crossed configuration relative to the contacts of the other pair to equalize heating of the pipe ends.

It is an object of the present invention to provide a forge welding method, which is able to interconnect tubular ends with a minimum of oxidized metal inclusions also in hazardous areas, such as on an offshore oil and/or gas production platform or on an oil and/or gas well drilling rig, in a safe and efficient manner and such that a high quality forge weld is created and the risk of explosion is limited to a minimum.

## SUMMARY OF THE INVENTION

The forge welding method according to the invention comprises the steps of arranging the tubular ends that are to be interconnected at a selected distance from each other in a space, which is substantially filled with a reducing flushing fluid mixture, heating each tubular end within said space and moving the tubular ends towards each other until the heated tubular ends contact each other and a forge weld is formed between the heated tubular ends wherein the flushing fluid mixture comprises less than 25% by volume of a reducing fluid and more than 75% by volume of a substantially inert gas.

It has surprisingly been found that a flushing fluid mixture comprising less than 25% by volume of a reducing fluid, such as hydrogen and/or carbon monoxide and/or a liquid reducing agent such as hydrogen peroxide, and more than 75% by volume of a substantially inert gas, such as nitrogen and/or argon and/or carbon dioxide, is non-explosive when it comes into contact with air and still

contains a sufficient amount of a reducing gas to effectively flush off any oxidised skin from the hot tubular ends that are to be interconnected. Preferably, the non-explosive flushing fluid mixture comprises between 2 and 15% by volume of reducing fluid and between 85 and 98% by volume of a substantially inert gas, and more preferably the mixture comprises about 5% by volume of reducing gas and about 95% by volume of a substantially inert gas. A preferred non-explosive flushing gas composition for forge welding of carbon steel tubulars comprises about 95% by volume of nitrogen and about 5% by volume of hydrogen, more in particular less than 5.7 % by volume of hydrogen and more than 94.3% by volume of nitrogen. The non-explosive flushing fluid mixture preferably comprises less than 100 ppm, and even more preferably less than, 15 ppm $H_2O$ and/or $O_2$.

When used in this specification and appended claims, the term substantially inert gas includes noble gases, like argon and helium, which are inert at any temperature as well as gases, such as nitrogen, which are inert at room temperature, but which react with oxygen at high temperature and/or in the presence of a catalyst.

A non-explosive flushing gas mixture may also be formed in-situ within said space surrounding the tubular ends by painting or spraying a liquid or solid reducing agent at the tubular ends then injecting an inert gas, such as pure nitrogen, into said space, whereupon the reducing agent is at least partly evaporated when the tubular ends are heated and the evaporated reducing agent is mixed with the injected inert gas to form in-situ a flushing gas mixture comprising less than 25% by volume of evaporated reducing agent and more than 75% by volume of substantially inert gas.

Suitably, the liquid reducing agent comprises a cleaning liquid, such as hydrochloric acid, and a reducing agent, such as hydrogen peroxide, borax powder and/or beryllium or alkaline hydrites, such as natrium-, potassium-, calcium-, or sodium-hydrites.

It is preferred that the tubular ends are heated by means of high frequency electrical heating while the tubular ends are maintained by a gripping assembly at a predetermined spacing of between 1 and 4 mm from each other and that use is made of electrical contacts that are pressed at circumferentially spaced intervals against the wall of each tubular adjacent to the tubular end such that the electrical contacts transmit a high frequency electrical current in a substantially circumferential direction in the tubular segment between the electrical contacts.

In order to further equalize the level of heating in circumferential direction it is preferred that tubular end is heated by at least two pairs of electrodes, wherein the electrodes of each pair of electrodes may be pressed at substantially diametrically opposite positions against the tubular wall and the different pairs of electrodes at each tubular end are activated in an alternating manner.

Suitably, two pairs of diametrically opposite electrodes are pressed at angular intervals of substantially 90 degrees against the tubular wall.

Alternatively, three pairs of diametrically opposite electrodes are pressed at angular intervals of substantially 60 degrees against the tubular wall.

If desired, four, five, six or more pairs of diametrically opposite electrodes may be used and activated in a alternating manner to further equalize the

level of heating of the pipe ends in circumferential direction.

The use of two or more pairs of electrodes reduces unequal heating of the pipe ends as a result of over-heating of the pipe wall in the direct vicinity of the electrode and a reduced heating of the pipe wall halfway between the electrodes.

Instead of heating the tubular ends by the above-described high frequency tangential current transmission technique the tubular ends may also be heated by a direct resistance heating wherein a large current is transmitted in an axial direction across the tubulars while they are pressed together, and/or pure induction heating wherein external and/or internal heating coils create an electromagnetic field which induces electrical currents in the tubulars.

The heating assembly may also be configured to give the forge welded tubular ends a post weld heat treatment wherein the tubular end are cooled down in accordance with a predetermined temperature decrease.

The assembly may also be equipped with water and/or forced air injectors to increase and/or control the cool down rate of the forge welded tubular ends.

Suitably, the quality of the forge weld formed between the interconnected tubulars is inspected by means of an Electro-Magnetic Acoustic Transmission weld inspection technique, which is known as EMAT, wherein an electromagnetic coils are placed adjacent to both sides of the forge welded joint and held at a predetermined distance from the tubulars during the inspection process. The absence of physical contact between the wall of the hot tubulars and the coils of the EMAT inspection tool

enables weld inspection immediately after the forge weld joint has been made.

## DESCRIPTION OF A PREFERRED EMBODIMENT

The invention will be described in more detail and by way of example with reference to the accompanying drawings in which:

Figure 1 depicts a cross-sectional view of a tubular end which is heated by two pairs of diametrically opposite electrodes; and

Figure 2 depicts a three-dimensional view of the tubular depicted in Figure before it is connected to another tubular by the forge welding method according to the invention.

Figure 1 shows an end of a steel tubular 1 around which two pairs of diametrically opposite electrodes 2, 3 and 4, 5 are arranged.

The first pair of electrodes 2, 3 is pressed against the outer surface of the tubular 1 and transmit a high frequency current 6 through the wall of the tubular as illustrated by arrows 7. An assembly of ferrite bars 8 serves to enhance the current density in the immediate vicinity of the ends of the tubular 1 and of the adjacent tubular (not shown).

Figure 2 shows how the ends 12, 12A of two adjacent tubulars 1 and 1A are each heated by two sets of diametrically opposite electrodes 2, 3, 4, 5 and 2A, 3A, 4A and 5A, respectively. The tubular ends 12 and 12A are located at a few millimetres distance from each other during the heat up phase. The larger spacing of current density arrows 7 and 7A midway between the electrodes 2,3 and 2A, 3A illustrate that the current density midway these electrodes is lower than the current density adjacent to the electrodes 2, 3 and 2A, 3A. This creates

variation in the heating rate of the tubular ends 12 and 12A and reduced heating in the area midway the electrodes 2, 3 and 2A, 3A. To reduce the irregular heating rate the electrodes 2, 3 and 2A, 3A are regularly lifted from the outer surface of the tubulars 1, 1A whereupon the other electrodes 4, 4A and 5, 5A are pressed against the outer surface of the tubulars 1, 1A and activated to transmit a high frequency current through the ends of the tubulars 1, 1A. By sequentially activating the two sets of diametrically opposite electrodes at each tubular end the irregularity of the heating of the tubular ends is reduced.

All the electrodes 2-5 and 2A-5A that are shown in Figure 2 may be pressed simultaneously against the spaced tubular ends 1 and 1A if the alternating current is controlled such that at during a first part of said cycle the diametrically opposite electrode pairs 2A, 3A and 4 and 5 transmit a positive electrical current as indicated by the + sign in Figure 2, whereas the other electrodes 2, 3, 4A and 5A transmit a negative electrical current as indicated by the - sign in Fig. 2. During a second part of the alternating current cycle, on the other hand, the electrodes 2A, 3A, 4 and 5 will transmit a negative electrical current, whereas the other electrodes 2, 3, 4A and 5A will transmit a positive current into the tubulars 1 and 1A, thereby heating the tubular ends 12 and 12A in a substantially equal manner.

The temperature of the heated tubular ends 12, 12A is monitored by an infrared temperature sensor and when the monitored temperature is suitable to make a forge weld the tubular ends 12, 12A are pressed onto each other such that a forge weld is made. The tubular ends 12,12A may be profiled and have a smaller wall thickness than other

parts of the tubulars 1, 1A in order to compensate for the deformation of the tubular end 12 and 12A that are red hot during the forge welding process, such that the forged welded tubulars 1, 1A have a uniform wall thickness and internal and external diameter.

During the heat up phase and while the ends of the tubulars 1, 1A are moved towards each other the tubular ends are encased, both internally and externally, in a chamber 10 which is filled with a non-explosive flushing gas mixture which comprises more than 75 vol% of nitrogen and less than 25 vol% of hydrogen. A preferred non-explosive flushing gas mixture for interconnecting carbon steel tubulars 1, 1A comprises about 5 vol% of hydrogen and about 95 vol% of nitrogen. The flushing gas pressure in the part of the chamber 10 outside the tubulars 1 and 1A is higher than the flushing gas pressure in the part of the chamber 10 within the interior the tubulars 1 and 1A, such that throughout the heating process the flushing gas flows along the ends of the tubulars 1, 1A as illustrated by arrows 11 until the ends of the tubulars are forged together.

The hydrogen in the flushing gas reacts with the oxygen in any oxidised skin on the ends 12, 12A of the to be interconnected tubulars 1, 1A so that the oxidised skin is at least substantially eliminated and clean metal parts are forged together with a minimal amount of corroded metal inclusions.

Laboratory experiments revealed that a good metallurgical bond between carbon steel tubulars is obtained by the above described forge welding method, wherein the flushing fluid contained about 5 vol% of hydrogen and about 95 vol% of nitrogen. The experiments

also confirmed the non-explosive nature of this flushing gas composition.

Preferably the tubular ends are clamped throughout the forge welding process to a gripping assembly, which maintains the tubular ends at a predetermined spacing of between 1 and 3 millimetres from each other during the heating phase and which comprises a mechanical stop which interrupts the axial movement of the heated tubular ends during the forge welding process when the heated tubular ends have moved along a predetermined distance towards and squeezed into each other such that a high quality forge weld is created without an excessive deformation of the heated tubular ends.

Suitably the electrodes 2-5 and 2A-5A may also be activated to give the forged tubular ends a post weld heat treatment. The electrical power 6 supplied to the electrodes during the post weld heat treatment will be lower than during the heat up phase before the forge welding operation and may be controlled in conjunction with the temperature measured by the infrared temperature sensor(s) such that the temperature of the forge welded tubular ends is decreased in accordance with a predetermined pattern.

The quality of the forge weld made may be inspected instantly after the weld has been made by means of a hybrid electromagnetic acoustic transmission technique which is known as EMAT and described in US patent Nos. 5,652,389; 5,760,307; 5,777,229 and 6,155,117. The EMAT technique makes use of an induction coil placed at one side of the welded joint, which coil induces magnetic fields that generate electromagnetic forces in the surface of the welded joint. These forces then produce a mechanical disturbance by coupling to the atomic lattice

through a scattering process. In electromagnetic acoustic generation, the conversion takes place within a skin depth of material, i.e. the metal surface is its own transducer. The reception takes place in a reciprocal way. When the elastic wave strikes the surface of the conductor in the presence of a magnetic field, induced currents are generated in the receiving coil, similar to the operation of an electric generator. An advantage of the EMAT weld inspection technology is that the inductive transmission and receiving coils do not have to contact the welded tubular. Thus the quality inspection can be done instantly after the forge weld is made, when the forge welded tubulars are still too hot to allow physical contact with an inspection probe.

The method and system according to the invention are particularly useful for welding oilfield and/or well tubulars at or near an oil/and or gas production rig. The tubulars may be production tubing strings of several kilometres length that are lowered into the well after the tubing sections have been welded together. Alternatively, the oilfield tubulars may be heating pipes that are inserted into a heater well which transmits heat into the surrounding kerogen and/or oil bearing formation to reduce the viscosity and/or pyrolyse the kerogen and/or other hydrocarbons in-situ. Such heating pipes may consist of a pair of co-axial pipes, which form an electrical circuit through which an electrical current is transmitted to produce heat.

It is preferred that such heater or production tubing strings are welded together when the welded tubulars extend in a substantially horizontal position on a tube assembly line at the earth surface whereupon the tubulars are bent and inserted into the heater or production well.

A suitable bending and insertion technique is disclosed in International patent applications WO 00/43630 and WO 00/43631, which are incorporated herein by reference. Preferably the well tubulars are welded together in a horizontal welding assembly near the wellhead and then coiled in a big loop that forms an arch of at least 270 degrees such that the proximal end of the tubing string extends vertically into the wellhead whereas the distal end of the tubing string extends horizontally through the welding assembly. Alternatively the welded well tubulars are welded together horizontally and then coiled in a big loop at a small distance from the wellhead. When the entire tubing string has been assembled and coiled into said big loop, the assembled tubing string is transported e.g. on a rail track to the wellhead and then inserted into the wellhead as disclosed in International patent application WO 00/43631. The latter tube assembling technique allows assembly of the tubular strings at a central welding assembly which is located at a central point above the oilfield where several tubular strings may be assembled and stored until they are transported to the wellhead and then quickly inserted into the well or wells such that the disruption of the well production and/or heating operations is minimal.

## CLAIMS

1. A method for interconnecting tubulars by forge welding, the method comprising: arranging the tubular ends that are to be interconnected at a selected distance from each other in a space, which is substantially filled with a flushing fluid mixture; heating each tubular end within said space and moving the tubular ends towards each other until a forge weld is formed between the heated tubular ends, wherein the flushing fluid mixture comprises a mixture comprising less than 25% by volume of a reducing fluid and more than 75% by volume of a substantially inert gas.

2. The method of claim 1, wherein the flushing fluid mixture is a mixture of a reducing fluid which comprises hydrogen and/or carbon monoxide and/or a liquid reducing agent and a substantially inert gas which comprises nitrogen and/or carbon dioxide and/or a noble gas such as argon.

3. The method of claim 1 or 2, wherein the flushing fluid mixture comprises between 2 and 15% by volume of reducing fluid and between 85 and 98% by volume of a substantially inert gas.

4. The method of claim 2, wherein a liquid or solid reducing agent is painted or sprayed at the tubular ends and an inert gas is injected into said space, whereupon the reducing agent is at least partly evaporated when the tubular ends are heated and the evaporated reducing agent is mixed with the injected inert gas to form in-situ a flushing gas mixture comprising less than 25% by volume

of evaporated reducing agent and more than 75% by volume of a substantially inert gas.

5. The method of claim 4, wherein the liquid or solid reducing agent comprises a cleaning liquid, such as hydrochloric acid, and a reducing agent, such as hydrogen peroxide, borax powder and/or an alkaline or beryllium hydrite.

6. The method of claim 1, wherein each tubular end is heated by means of high frequency electrical heating wherein use is made of electrical contacts that are pressed at circumferentially spaced intervals against the wall of each tubular adjacent to the tubular end such that the electrical contacts transmit a high frequency electrical current in a substantially circumferential direction through the tubular segment between the electrical contacts.

7. The method of claim 6, wherein the tubular ends are heated by at least two pairs of electrodes and the electrodes of each pair of electrodes are pressed at substantially diametrically opposite positions against the tubular wall.

8. The method of claim 7, wherein the different pairs of diametrically opposite electrodes at each tubular end are activated in an alternating manner.

9. The method of claim 7 or 8, wherein two pairs of diametrically opposite electrodes are pressed at angular intervals of substantially 90 degrees against the tubular wall.

10. The method of claim 7 or 8, wherein three pairs of diametrically opposite electrodes are pressed at angular intervals of substantially 60 degrees against the tubular wall.

11. The method of any one of claims 1-10, wherein the tubulars are oilfield or well tubulars.

12. The method of any one of claims 1-11, wherein the quality of the forge weld formed between the interconnected tubulars is inspected by means of an electromagnetic acoustic inspection technique, which is known as EMAT and wherein induction coils are placed at both sides of the forge welded, which coils are held at a predetermined distance from the tubulars during the inspection process.

13. A system for use in the method of claim 1, the system comprising a reducing flushing fluid supply from which in use a reducing flushing fluid comprising less than 25 vol% of an reducing fluid and more than 75 vol% of a substantially inert gas is injected into a cavity; means for heating a pair of tubular ends that are to be interconnected to a selected temperature; and a gripping assembly for moving the tubular ends towards each other while reducing fluid present in the gap left between the heated tubular ends until the heated tubular ends contact each other and a forge weld is formed between the heated tubular ends.

14. The system of claim 13, wherein the means for heating the tubular ends comprise a plurality of electrical contacts which are in use arranged within the cavity and are pressed at circumferentially spaced intervals against the wall of each tubular adjacent to the tubular end, a high frequency electrical current supply connected to the electrical contacts for transmitting in use a high frequency electrical current in a substantially circumferential direction through the tubular segment between the electrical contacts.

15. The system of claim 13 or 14, wherein the gripping assembly is configured to maintain the tubular ends at a predetermined spacing during the heating phase and comprises a mechanical stop which is configured to interrupt the axial movement of the heated tubular ends during the forge welding process when the heated tubular ends have moved along a predetermined distance towards and squeezed into each other.

ABSTRACT

METHOD FOR INTERCONNECTING TUBULARS BY FORGE WELDING

In a forge welding method for joining e.g. oilfield tubulars a reducing flushing fluid mixture is injected into a space surrounding the heated tubular ends while the tubular ends are moved towards each other until a forge weld is formed between the heated tubular ends, wherein the reducing flushing fluid mixture comprises a non-explosive mixture comprising less than 25% by volume of a reducing fluid and more than 75% by volume of a substantially inert gas. The flushing gas mixture preferably comprises about 95 vol% of a substantially inert gas, such as nitrogen and/or argon and/or carbon dioxide, and about 5 vol% of reducing fluid, such as hydrogen and/or carbon monoxide and/or a reducing liquid acid, in order to create a mixture which is non-explosive to enable use in a hazardous area, but which still has sufficient reducing activity to reduce and remove any oxidised metal skin from the hot tubular ends that are forged together, such that a high quality forge weld is created with a minimal amount of oxidised metal inclusions.

(FIG. 2)

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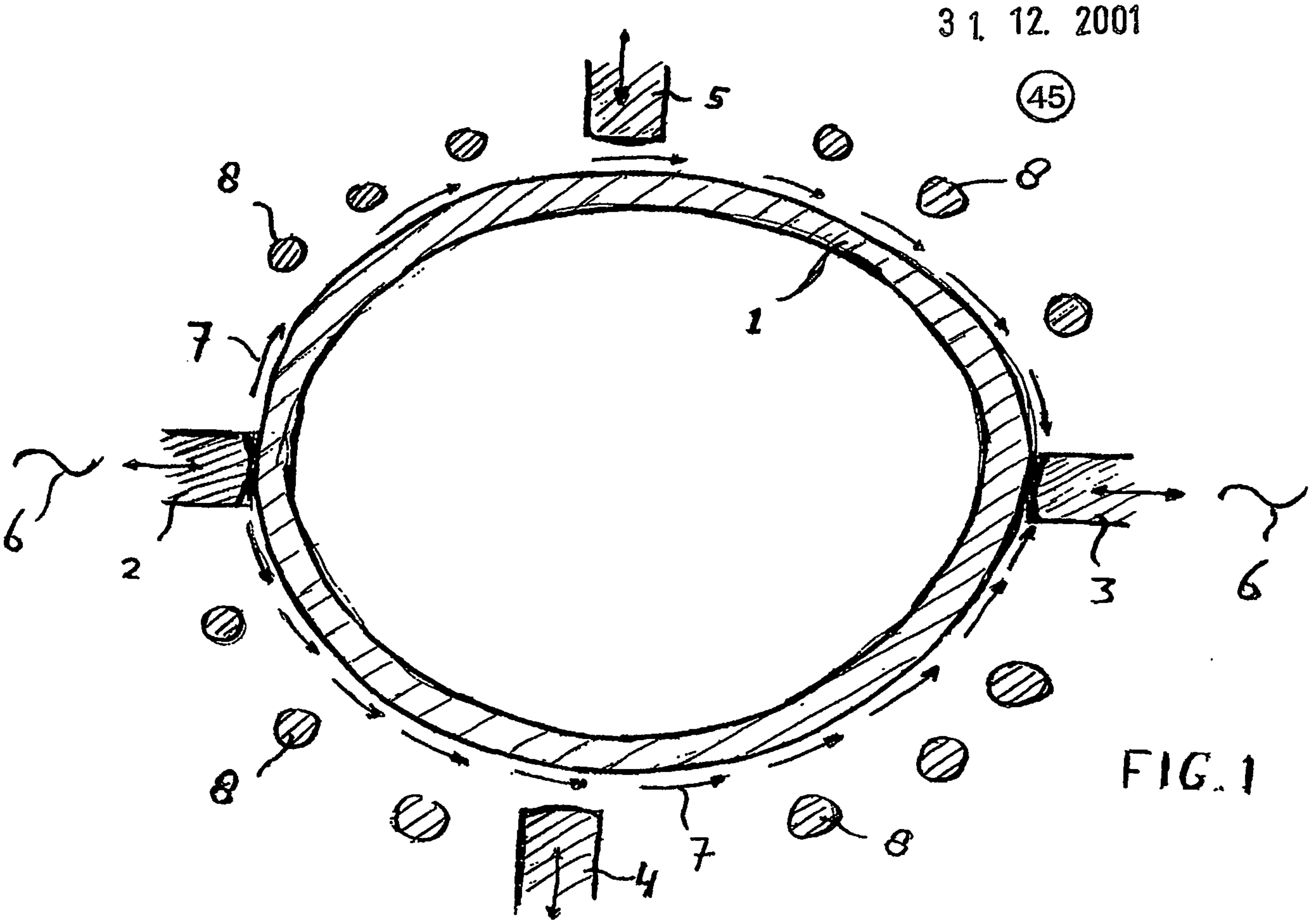


FIG. 1

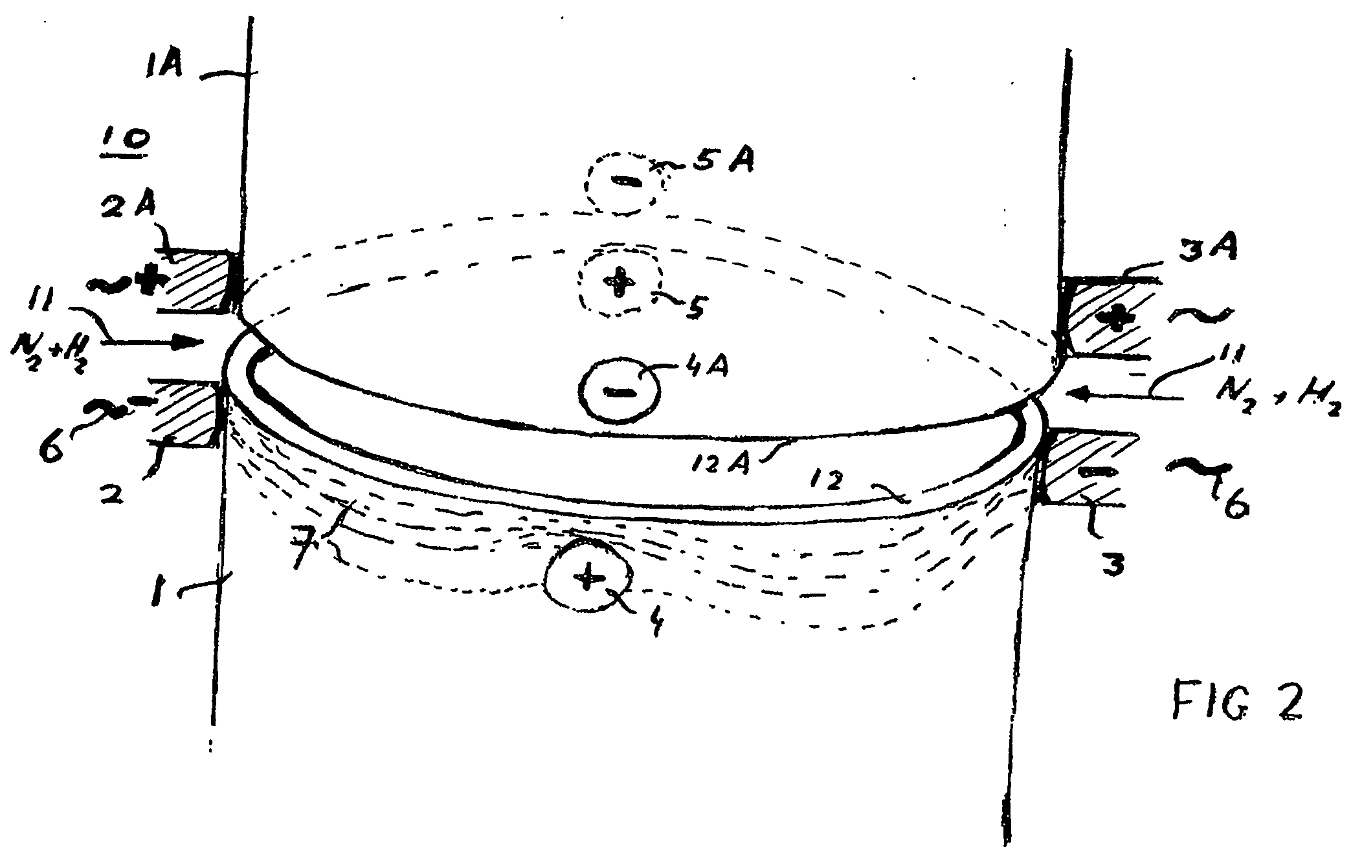


FIG 2